Demonstration of an integrated LiNbO3 Synchronized Double Phase Modulator and its Applications to Dual-Pump Fiber Optical Parametric Amplifiers and Wavelength Converters

A. Vedadi, N. Grossard, J. Hauden, E. Lantz, H. Maillotte, T. Sylvestre

Demonstration of an Integrated $LiNbO_3$ Synchronized Double Phase Modulator and Its Application to Dual-Pump Fiber Optical Parametric Amplifiers and Wavelength Converters

Armand A. Vedadi, Nicolas Grossard, Jérome Hauden, *Member, OSA*, Eric Lantz, Hervé Maillotte, and Thibaut Sylvestre, *Member, OSA*

***Abstract*—We report the fabrication of an integrated $LiNbO_3$ Y-junction synchronized double phase modulator fully packaged for RF-application up to 40 GHz. This optical modulator allows for delivering simultaneously counter-phase high-speed modulation and coupling for two input channels. It was designed for application to fiber-optical parametric amplifier and wavelength converters for suppressing idler spectral broadening and signal gain distortion caused by phase modulation itself. With this component, Idler spectral broadening suppression is experimentally demonstrated over all the parametric gain band of a two-pump parametric amplifier operating in the 1.55-μm region. In addition, we present a useful technique for straightforward and full coupling of the pumps and the signal.**

***Index Terms*—Communications, fiber optics, fiber optics amplifiers and oscillators, fibers, nonlinear optics.**

I. Introduction

LITHIUM NIOBATE ($LiNbO_3$) optical modulators are now widely used in transmission networks and high bandwidth optical applications because of their strong potential and versatility for delivering high-speed modulation solutions [1], [2]. For instance, they are currently used in broadband fiber optical parametric amplifiers (FOPAs) for suppressing stimulated Brillouin scattering (SBS) of the high-power continuous-wave pumps [3]. To this end, the most commonly used approach is to increase the SBS threshold by modulating of the pump phase with a pseudo-ramdom bit sequence (PRBS) or a multi-frequency scheme with a maximum frequency modulation of a few gigahertz, while keeping the maximum spectral density in a limited frequency range. However, this optical modulation applied to the pump phase induces in turn some limitations on system performances, in particular, on the bit-error rate (BER) and the Q-value [4]–[7]. First, pump phase modulation induces a detrimental spectral broadening of the converted signal (idler) wave generated by four-wave mixing (FWM) [8]. Second, as it has recently been demonstrated theoretically and experimentally [4], [9] pump phase modulation can generate signal gain distortions which depend on the rise/fall time of the optical modulator. To overcome these obstacles, several techniques have been proposed and demonstrated. For instance, it is possible to reduce idler spectral broadening in single-pump FOPAs by using binary-phase shift keying phase modulation of the pump [10], [11]. Quite recently, Kylemark *et al.* [12] showed that although the Q-value of data amplified by a periodic and deterministic gain may be considerably degraded, the BER can still be relatively unaffected if ON-OFF-keyed (OOK) data is amplified. However, using two-pump FOPAs, both idler spectral broadening and parametric gain distortions can in principle be totally cancelled by using a dual-wavelength counter-phasing modulation scheme [13]–[16]. This latter scheme theoretically ensures that both the idler frequency chirp and the signal gain distortion induced by one pump are exactly balanced by an opposite frequency chirp induced by the second pump, paving the way for fully-transparent parametric devices. Counter phase modulation of the pumps has been achieved either by using two PMs driven with two complementary patterns, or a single PM and an accurate optical delay line between the two pumps [14], [15]. In both cases, however, it is difficult in practice to synchronize and keep the pump in phase opposition because of the short PM rise/fall time ($\simeq$30 ps). In a recent communication, we reported the fabrication of a novel $LiNbO_3$-based electro-optic PM that allows for the simultaneous achievement of counter-phase modulation, synchronization and coupling of two channels for two-pump FOPA [17]. In this paper, we demonstrate the effectiveness of this synchronized double-phase modulator (SDPM) over the whole flat gain band of a two-pump FOPA through high-resolution spectral analysis of the idler and signal waves. In addition, we describe a new scheme to allow for the achievement of direct pump signal coupling within the parametric amplifier without any pump loss. Our scheme simply relies on the use of optical circulator instead of fused tap coupler. This paper is organized as follows. In Section II, we will briefly describe the fabrication process of our SDPM and we will characterize its mode of

Manuscript received August 23, 2007; revised December 10, 2007. This work was supported in part by the Conseil Régional de Franche-comté and by the European INTERREG Program IIIA (S 019). This work was performed at the Département d'Optique P. M. Duffieux, Institut FEMTO-ST, Université de Franche-Comté, CNRS UMR 6174, F-25030 Besançon cedex, France.

A. Vedadi is with the Institute of Advanced Telecommunications (IAT), Swansea University, Swansea SA2 8PP, Wales, U.K. (e-mail: a.vedadi@swansea.ac.uk).

N. Grossard and J. Hauden are with PHOTLINE Technologies, F-25001 Besançon, France (e-mail: nicolas.grossard@photline.com; jerome.hauden@photline.com).

E. Lantz, H. Maillotte, and T. Sylvestre are with the Département d'Optique P.M. Duffieux, Institut FEMTO-ST, Université de Franche-Comté, CNRS UMR 6174, F-25030 Besançon cedex, France (e-mail: thibaut.sylvestre@univ-fcomte.fr).

Digital Object Identifier 10.1109/JLT.2007.916497

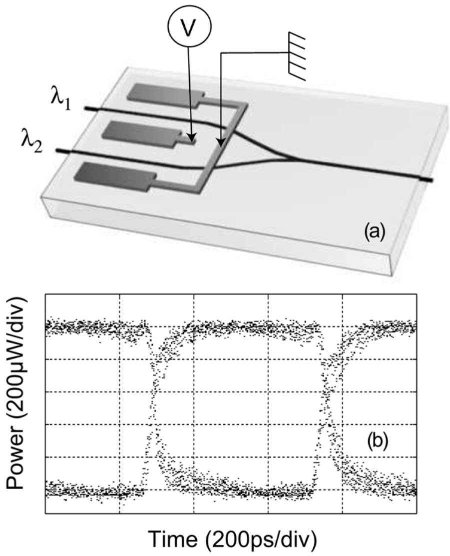


Fig. 1. (a) Scheme of the X-cut SDPM. (b) Output 1 Gbits/s NRZ-eye diagram in a Mach–Zehnder interferometer configuration.

operation in a Mach–Zhender configuration. Then, we will present the fiber optical parametric amplifier incorporating the SDPM and providing the main experimental results by comparing the in-phase to the counter phase scheme. Finally, we will conclude and discuss further studies.

II. Syncronized Double Phase Modulator

The $LiNbO_3$ modulator was designed and fabricated to meet the requirements of ultra-high bandwidth optical applications. It consists of a synchronized double broadband PM integrated on X-cut $LiNbO_3$. Fig. 1(a) is a sketch of the device. It is made up of two input waveguides, linked by a Y-junction to a single output. All the waveguides are single-mode in the 1.55-μm telecom window. A set of push-pull broadband coplanar RF-electrodes is put on top of both parallel waveguides. Thanks to a precise geometrical arrangement, they provide an RF-electric field of opposite sign in each optical arm. As an external electric signal is applied, each waveguide is the location of an index modulation that is the exact opposite, in amplitude and phase, of the modulation that takes place in the other waveguide. A Y-coupler is set at the output for optical mixing. The device acts as two automatically synchronized and coupled broadband counter phase PMs. It is fully packaged for RF-application up to 40 GHz. When launching the same monochromatic source at both inputs, the SDPM behaves like a Mach–Zehnder interferometer. We performed the experiment by using as a signal source a frequency-stabilized DFB fiber laser operating at 1549.74 nm (linewidth $<$ 45 kHz) and a fast 40-GHz digital oscilloscope (Tektronix CSA 8000 Communications Signal Analyzer). Fig. 1(b) shows the intensity modulation detected at the output of the device driven by a 1 Gbits/s (PRBS) $2^7 - 1$ non-return-to zero (NRZ) pattern. As it can be seen, the clearly opened eye diagram reveals the counter-phase modulation that has occurred on each waveguide of the SDPM. This simple experiment shows that our double phase modulator can be used as a conventional fast intensity modulator as well. Note also that, as this $LiNbO_3$ modulator is bidirectional, it can deliver from one channel two out-of-phase output channels.

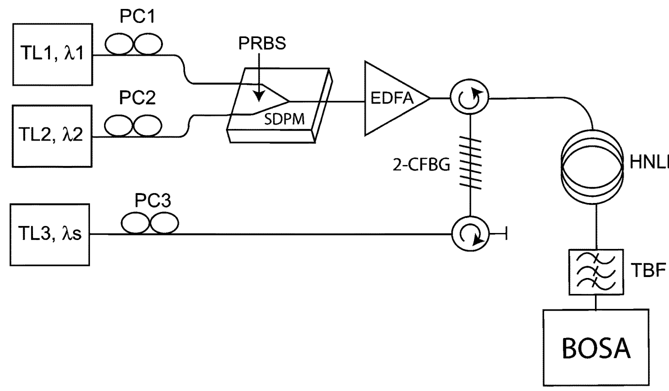


Fig. 2. Experimental setup of the counter-phase modulated two-pump fiber optical parametric amplifier. TL: tunable laser. EDFA: Erbium-doped fiber amplifier. 2-CFBG: dual-channel fiber bragg grating. PC: polarization controller. HNLF: highly-nonlinear fiber. BOSA: Brillouin optical spectrum analyzer.

III. Experimental Setup

The SDPM was then incorporated in a two-pump FOPA. The experimental setup is depicted in Fig. 2. Two tunable lasers (TL1 and TL2) at $\lambda_1 = 1536$ nm and $\lambda_2 = 1566$ nm were used as parametric pumps. They were copolarized using polarization controllers and launched together into the SDPM. It was electrically driven by a PRBS pattern generator at 2-Gbits/s with a $2^{15} - 1$ pattern with a corresponding rise/fall time of about 30 ps. We have checked that this frequency modulation is large enough for raising the Brillouin threshold power above the pump powers.

At the SDPM's output, the synchronized counter-phase modulated TLs are amplified using a single 33-dBm-high-power EDFA. A dual-channel fiber Bragg grating (2-CFBG) centered at λ_1 and λ_2 has been specially developed to remove any broadband ASE noise in the amplification band and around the two pump frequencies. This is indeed crucial for FOPA to have a large pump optical signal-to-noise ratio (OSNR) for minimizing the pump-to-signal noise transfer due to FWM and to keep the noise figure below 4–5 dB [7], [18]. This custom-made filter consists of two sub-gratings written in a single piece of fiber at the same location, thus keeping the pumps in synchronization. Each channel linewidth is 0.25 nm at -3 dB. Fig. 3 shows the reflectivity of the two-channel FBG obtained with a broadband ASE source. As a signal source, we use an additional continuous-wave tunable laser (TL3) that might be directly intensity modulated up to a few hundred megahertz. Instead of using a fiber tap coupler, as in most previous experiments, the signal is coupled to the two pumps at the other end of the 2-CFBG by use of an additional optical circulator. This latter scheme provides a much more efficient coupling of the signal and the pumps compared to a standard coupler, because of the 2-CFBG reflectivity at the pumps wavelengths and transmission at the signal wavelength. The 2P-FOPA acts therefore as a real amplifying device in a black-box configuration, since no signal power is lost before parametric amplification. The amplifier medium is a 500-m-long highly nonlinear fiber (HNLF) with nonlinear coefficient $\gamma = 10\ \mathrm{W^{-1}km^{-1}}$ and zero-dispersion wavelength $\lambda_0 = 1551.4$ nm. The fiber absorption is $\alpha = 0.58\ \mathrm{dB.km^{-1}}$ at 1550 nm. The third and fourth dis-

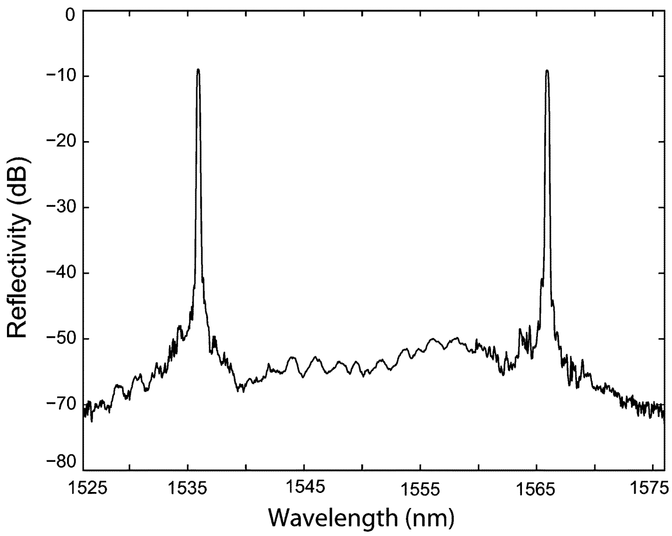


Fig. 3. Reflectivity spectrum of the dual-channel FBG (resolution = 0.1 nm).

persion coefficients were measured as $\beta_3 = 5.3 \times 10^{-41}\mathrm{s}^3\mathrm{m}^{-1}$ and $\beta_4 = -6.4 \times 10^{-56}\mathrm{s}^4\mathrm{m}^{-1}$, using a recent accurate method [19]. Note that, in our case, HNLF offers a strong advantage with respect to conventional dispersion shifted fibers because of their lower dispersion slope and higher nonlinear coefficient [20]. In particular, the HNLF has a low dispersion slope ($D_S = 0.033$ ps.nm^{-2}km^{-1}) which prevents from residual temporal walk-off between the two pumps in the region of zero-dispersion wavelength and keeps the synchronization of the counter-phasing scheme all along the amplifier span. TL1 and TL2 powers were tuned to reach 23 dBm for each pump below the Brillouin threshold power. At the output end, the amplified signal and idler waves are independently analyzed using a tunable bandpass filter (TB9, 1-nm bandwidth) and a Brillouin optical spectrum analyzer (BOSA) with a 10-MHz high resolution. The counter phasing PM scheme is finally compared to the in-phase PM scheme simply by multiplexing TL1 and TL2 together in one arm of the SDPM using a 50/50 fiber coupler.

IV. Results

Fig. 4(a) shows the experimentally-measured gain band. The 2P-FOPA exhibits a flat 9-dB mean gain over approximately 20-nm band, from 1540 to 1560 nm. Note on Fig. 3(a) that the FOPA bandwidth is not very wide. But this is in good agreement with the theoretically predicted gain spectrum (solid curve) using the standard analytical six-waves model [16], [21]. Since it takes into account the two non-phase-matched sidebands generated by four-wave mixing symmetrically with respect to the pump frequencies, it provides the exact parametric gain solution near the pumps compared to the conventional four-wave mixing model. Note also that fiber absorption as well as the misalignment between the pumps, the signal and the idler polarizations due to a low PMD ($<$0.1 ps $\cdot \sqrt{(\mathrm{km})^{-1}}$) are known to uniformly decrease the gain bandwidth [22]. To account for these detrimental effects, the fiber effective interaction length was set at 440 m for the analytical calculation, instead of the actual 500 m length of the HNLF. Fig. 4(b) illustrates the FOPA

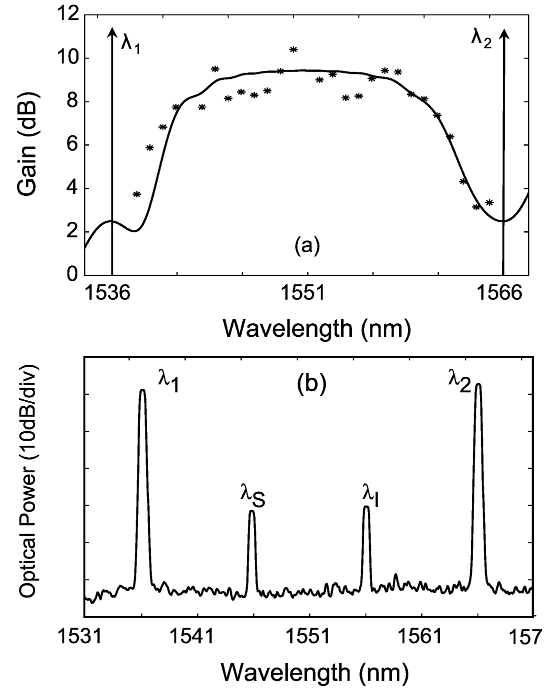


Fig. 4. (a) Experimentally-measured gain band of the 2P-FOPA (stars) and theoretically-predicted one (solid curve). (b) Low resolution 2P-FOPA output spectrum showing the two pumps, the amplified signal, and the generated idler, respectively.

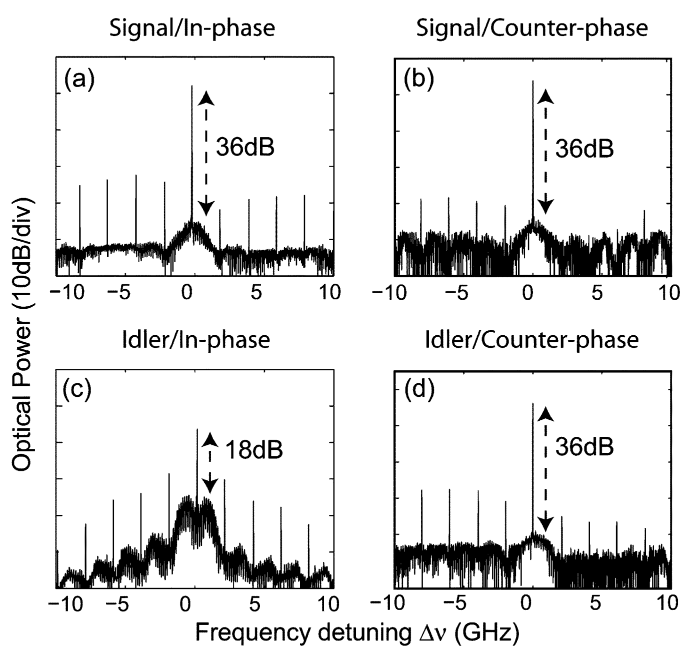


Fig. 5. (a and c) Signal and Idler spectra when the pumps are in-phase modulated and (b and d) counter-phase modulated using the synchronized double phase modulator.

output spectrum with both pumps recorded with a conventional optical spectrum analyzer (resolution: 1 nm), the amplified signal at $\lambda_S = 1546$ nm and its idler counterpart generated at $\lambda_I = 1556$ nm. The input signal power is 5 μW (-23 dBm) and the gain was assessed to about 10 dB.

Fig. 5(a) and (c) show the corresponding signal and idler high-resolution spectra using the BOSA when the pumps are

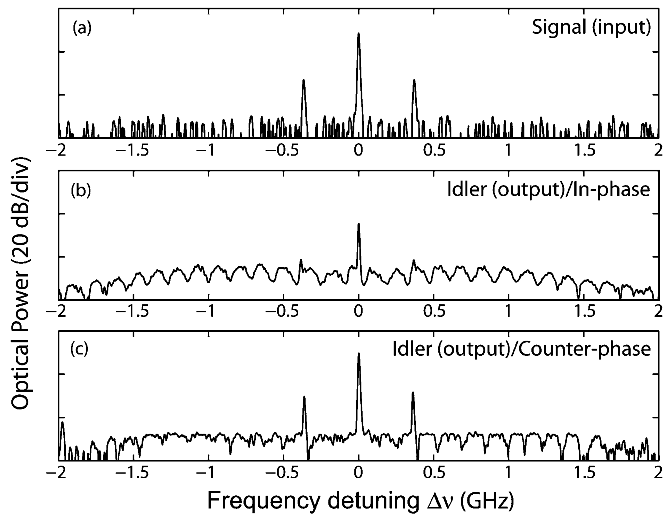


Fig. 6. (a) Modulated signal spectrum at the FOPA input. (b) Output Idler spectrum when the pumps are in-phase modulated. (c) Counter-phase modulated using the SPDM.

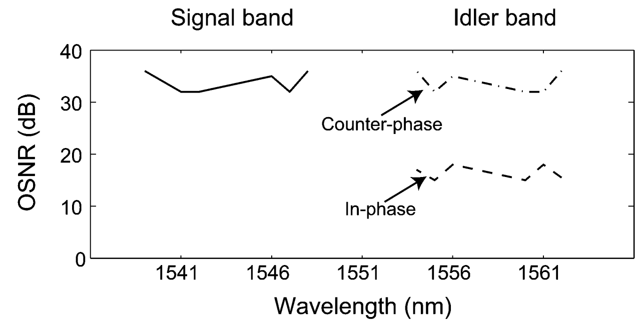


Fig. 7. Ratio of the peak power to the pedestal noise (OSNR) versus the wavelength for signal (left side, solid curve) and the idler for in-phase (right side, dashed curve) and counter-phase (right side, dashed-dot curve) modulated pumps.

co-phase modulated, i.e., when they are launched together in one arm the SDPM. By comparing Fig. 5(a) and (c), we can clearly see the substantial deterioration with a corresponding noise pedestal for the idler with respect to the output signal. The idler peak power is at least 10 dB lower, while the ratio to the pedestal noise is 18 dB lower compared to the output signal. With the counter-phasing method, however, we can see on Fig. 5(b) and (d) that the idler spectral broadening is totally cancelled and the ratio of the idler to the pedestal noise is comparable to that of the output signal. The remaining pedestal and sideband peaks at every 2 GHz (the frequency carrier of the PRBS modulation) seen on all figures can be attributed due to the pump-to-signal noise transfer and to a non-perfect PRBS pattern. To get better insight, we have also investigated the spectral content of the idler generated from an intensity-modulated signal. Indeed, when a current is applied to the TL3 diode, two low power sidebands located at 380 MHz from the carrier were created. A high resolution BOSA spectrum of the input signal, shown in Fig. 6(a), reveals those two modulation sidebands. Fig. 6(b) shows the wavelength converted idler when the pumps are co-phase modulated. On one hand, we can notice that the original signal sidebands are almost lost in the noise induced by the transfer of the two pumps PM. On the other hand, when the pumps are counter-phase modulated, Fig. 6(c) shows that the original signal sidebands are well preserved on the wavelength converted idler, which confirms the effectiveness of the SDPM.

Tuning λ_S from 1539 to 1548 nm, we have verified the idler broadening cancellation over approximately half of the inner band between the two pumps. These results are summarized on Fig. 7 which depicts the ratio of the idler peak power to the pedestal noise versus the wavelength (OSNR), for the in-phase (dashed curve) and counter-phase (dashed-dot curve) modulation scheme. The comparison with the signal peak power to the pedestal noise (left side, solid curve) shows that by using the SDPM, the two-pump FOPA acts as a fully transparent wavelength converter.

V. Conclusion

We have demonstrated a novel two-pump fiber optical parametric amplifier architecture including a single $LiNbO_3$ synchronized double phase modulator for pump SBS suppression. With this modulator, we straightforwardly achieved synchronized counter-phase modulation of the parametric pumps and suppression of the idler spectral broadening. The counter-phasing method was checked over all the parametric gain band. We may expect that our 2P-FOPA that uses the SDPM also suppresses the parametric gain distortion and subsequently the BER degradation and the Q-penalty due to pump phase modulation, as theoretically predicted [16], paving the way for future fully-transparent parametric devices.

Acknowledgment

The authors would like to thank F. Patois and J. M. Merolla for the loan of the Brillouin optical spectrum analyser (BOSA) and fruitful discussions.

References

[1] E. Woolen, K. Kissa, A. Yi-Yan, E. Murphy, D. Lafaw, P. Hallemeier, D. Maack, D. Attanasio, D. Fritz, G. McBrien, and D. Bossi, "A review of lithium niobate modulators for fiber-optic communications systems," *IEEE J. Sel. Topics Quantum Electron.*, vol. 6, no. 1, pp. 69–82, Jan. 2000.

[2] G. L. Li and P. K. L. Yu, "Optical intensity modulators for digital and analog applications," *J. Lightw. Technol.*, vol. 21, no. 1, pp. 2010–2030, Jan. 2003.

[3] J. Hansryd, P. A. Andrekson, M. Westlund, J. Lie, and P.-O. Hedekvist, "Fiber-based optical parametric amplifiers and their applications," *IEEE. J. Selected Topics Quantum Electron.*, vol. 8, no. 3, pp. 506–520, May/Jun. 2002.

[4] A. Mussot, A. Durecu-Legrand, E. Lantz, C. Simmoneau, D. Bayart, H. Maillotte, and T. Sylvestre, "Impact of pump phase modulation on the gain of fiber parametric amplifier," *IEEE Photon. Technol. Lett.*, vol. 16, no. 5, pp. 1289–1291, May 2004.

[5] J. C. Boggio, A. Guimaraes, F. Callegari, J. Marconi, and H. Fragnito, "Q penalties due to pump phase modulation and pump RIN in fiber optic parametric amplifiers with non-uniform dispersion," *Opt. Commun.*, vol. 249, pp. 451–472, 2005.

[6] F. Yaman, Q. Lin, S. Radic, and G. P. Agrawal, "Impact of pump-phase modulation on dual-pump fiber-optic parametric amplifiers and wavelength converters," *IEEE Photon. Technol. Lett.*, vol. 17, no. 10, pp. 2053–2055, Oct. 2005.

[7] P. Kylemark, M. Karlsson, and P. A. Andrekson, "Impact of phase modulation and filter characteristics on dual-pumped fiber-optical parametric amplification," *IEEE Photon. Technol. Lett.*, vol. 18, no. 2, pp. 439–441, Jan. 2006.

[8] J. Hansryd and P. A. Andrekson, "Broad-band continuous-wave-pumped fiber optical parametric amplifier with 49-dB gain and wavelength-conversion efficiency," *IEEE Photon. Technol. Lett.*, vol. 13, no. 3, pp. 194–196, Mar. 2001.

[9] A. Durecu-Legrand, A. Mussot, C. Simmoneau, D. Bayart, T. Sylvestre, E. Lantz, and H. Maillotte, “Impact of pump phase modulation on system performances of fiber optical parametric amplifiers,” *IEE Electron. Lett.*, vol. 41, no. 6, pp. 83–84, Mar. 2005.

[10] T. Tanemura, H. C. Lim, and K. Kikuchi, “Suppression of idler spectral broadening in highly efficient fiber four wave mixing by binary phase shift keying modulation of pump wave,” *IEEE Photon. Technol. Lett.*, vol. 13, no. 12, pp. 1328–1330, Dec. 2001.

[11] S. Radic, C. J. McKinstrie, R. M. Jopson, A. H. Gnauck, J. C. Centanni, and A. R. Chraplyvy, “Performance of fiber parametric-processing devices using binary-phase-shift-keyed pump modulation,” *IEEE Photon. Technol. Lett.*, vol. 16, no. 2, pp. 548–550, Feb. 2004.

[12] P. Kylemark, J. Ren, Y. Myslivets, N. Alic, S. Radic, P. A. Andrekson, and M. Karlsson, “Impact of pump phase-modulation on the bit-error rate in fiber-optical parametric-amplifier-based systems,” *IEEE Photon. Technol. Lett.*, vol. 19, no. 2, pp. 79–81, Jan. 2007.

[13] R. Jopson, “Polarization-insensitive optical four-photon mixer with orthogonally-polarized pump signals,” U.S. Patent No. 5 386 314, Jan. 31, 1995.

[14] M. C. Ho, M. E. Marhic, K. K. Y. Wong, and L. G. Kazovsky, “Narrow-linewidth idler generation in fiber four-wave mixing and parametric amplification by dithering two pumps in opposition of phase,” *J. Lightw. Technol.*, vol. 20, no. 3, pp. 469–476, Mar. 2002.

[15] S. Radic, R. M. Jopson, A. Gnauck, C. J. McKinstrie, J. C. Centanni, and A. R. Chraplyvy, “Stimulated brillouin scattering suppression using a single modulator in two-pump parametric architectures,” presented at the Opt. Fiber Commun., Anaheim, CA, 2005.

[16] A. Vedadi, A. Mussot, E. Lantz, H. Maillotte, and T. Sylvestre, “Theoretical study of gain distortions in dual-pump fiber optical parametric amplifiers,” *Optics. Commun.*, vol. 267, pp. 244–252, 2006.

[17] A. Vedadi, J.-C. Beugnot, E. Lantz, H. Maillotte, J. Hauden, and T. Sylvestre, “Fiber optical parametric amplifier based on a novel LiNbOs synchronized double phase modulator,” presented at the Opt. Fiber Commun., Anaheim, CA, 2007.

[18] A. Durecu-Legrand, C. Simmoneau, D. Bayart, A. Mussot, E. Lantz, T. Sylvestre, and H. Maillotte, “Impact of pump OSNR on noise figure for fiber-optical parametric amplifiers,” *IEEE Photon. Tech. Lett.*, vol. 17, no. 6, pp. 1178–1180, Jun. 2005.

[19] B. Auguie, A. Mussot, A. Boucon, E. Lantz, and T. Sylvestre, “Ultralow chromatic dispersion measurement of optical fibers with a tunable fiber laser,” *IEEE Photon. Tech. Lett.*, vol. 18, no. 17, pp. 1825–1827, Sep. 2006.

[20] T. Okuno, M. Onishi, T. Kashiwada, S. Ishikawa, and M. Nishimura, “Silica-based functional fibers with enhanced nonlinearity and their applications,” *IEEE J. Sel. Topics Quantum Electron.*, vol. 5, no. 5, pp. 1385–1391, Sep. 1999.

[21] C. J. McKinstrie, R. S. , and A. R. Chraplyvy, “Parametric amplifiers driven by two pump waves,” *IEEE J. Sel. Topics Quantum Electon.*, vol. 8, no. 3, pp. 538–547, May/Jun. 2002.

[22] F. Yaman, Q. Lin, and G. P. Agrawal, “Effects of polarization-mode dispersion in dual-pump fiber-optic parametric amplifiers,” *IEEE Photon. Technol. Lett.*, vol. 16, no. 2, pp. 431–433, Feb. 2004.

Armand A. Vedadi received the M.Sc. degree from the Institute of National Telecommunications (INT), Paris, France, in 2004.

Since October 2007, he has been with the Institute of Advanced Telecommunications (IAT), Swansea University, Swansea, U.K. From 2004 to 2007, he worked with the Nonlinear Optics Team, FEMTO-ST Institute, the Université de Franche-Comté, Besançon, France. His research interests focus on optical parametric amplification and nonlinear effects in optical fibres.

Nicolas Grossard was born in France in November 1974. He received the Ph.D. degree in “Sciences Pour l’Ingénieur” from the Université of Franche-Comté, Besançon, France, in 2001.

In 2001, he joined Photline Technologies, Besançon, France, as a Process Engineer involved in the development of lithium niobate electro-optic modulators. His current research activities include simulations and design of optical waveguides.

Jérome Hauden received the Ph.D. degree in electrical engineering from the Université de Franche-Comté, Besançon, France, in 1995.

After a Postdoctoral position with Ginzton Lab, Stanford University, Stanford, CA, in 1995–1996, he was an Associate Professor in optoelectronics with the Université de Franche-Comté. He spent two years at the GeorgiaTech Lorraine-CNRS Lab in 1998–2000. His research interests include lithium niobate integrated optics for electro-optic modulation and all-optical guided conversions. In 2000, he founded Photline Technologies, where he is Research and Technology Manager.

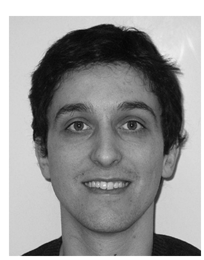
Dr. Hauden is a member of the Optical Society of America.

Eric Lantz was born in Paris, France, in 1957. He received the Ph.D. degree from the Université de Franche-Comté, Besançon, France, in 1989, where he studied super-resolution in optical microscopy by inverse problem method.

From 1979 to 1985, he worked in the field of solar energy and heat pumps. In 1986, he joined the Laboratoire d’Optique P.M. Duffieux, the Université de Franche-Comté, Besançon, France. In 2001, he was appointed Professor of Physics with the Département d’Optique, the Université de Franche-Comté. He is involved with studies of traveling-wave parametric image amplification in nonlinear crystals and its applications ranging from to time-gating to quantum imaging. His current research interests include parametric amplification in optical fibers, spatial solitons, and optimal photon counting strategies with EMCCD cameras.

Hervé Maillotte was born in Besançon, France, in 1962. He received the Ph.D. degree in engineering science from the Université de Franche-Comté, Besançon, France, in 1990.

After about two years with a laser company and a spacecraft firm, he joined the Laboratoire d’Optique P.M. Duffieux, in 1991, as a CNRS Researcher, where he initiated a research project on parametric amplification in optical fibres. He is also involved with the development of third-order nonlinear organic materials and Z-scan measurements, spatial soliton in Kerr and photorefractive media, four-wave mixing and stimulated scattering in conventional and microstructured fibers, supercontinuum generation, opto-acoustics in microstructured fibers. Since 2005, he has been working at the head of the Département d’Optique P.M. Duffieux, FEMTO-ST Institute.



Thibaut Sylvestre was born in Besançon, France, in 1973. He received the M.Sc. and the Ph.D. degrees in “Sciences Pour l’Ingénieur” from the Université de Franche-Comté, Besançon, France, in 1995 and 1999, respectively.

He then started a 2-year postdoctoral stay abroad in the field of nonlinear fiber optics with the Optics and Acoustics Department , Université libre de Bruxelles (ULB), Brussels, Belgium. In 2001, he was appointed a full-time researcher in charge with the Centre National de la Recherche Scientifique (CNRS), FEMTO-ST institute, Besançon, France. He is involved with theoretical and experimental studies of fundamental nonlinear optical phenomena with the aim of investigating potential applications to telecommunications and other domains.

Dr. Sylvestre is a member of the Optical Society of America.